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CONCEPTUAL STUDY OF A MODULE CONNECTOR SYSTEM FOR A DEPLOYABLE WATERFRONT FACILITY

Abstract This report presents three conceptual methods for connecting barge-like modules in open seas. The goal is to identify new technology and materials for use in the development of a high strength connecting system that can be installed fast in open seas with limited heavy lift equipment. The three concepts presented are: (a) flat, flexible connector with pneumatic bladders, (b) cylindrical, flexible connector with pneumatic bladders, and (c) flat, flexible connector with a mechanical closure. Major components of each concept are described to demonstrate the mechanism of the concept. Preliminary calculations are provided to show the strength and holding capacity. The advantages and disadvantages of each concept are discussed. Research and development requirement for each concept are discussed. Research and development requirement for each concept are identified. A test procedure to verify the feasibility of the concepts is also proposed.

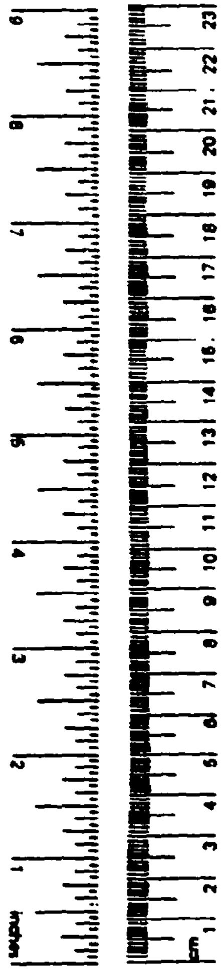
NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043-4328

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

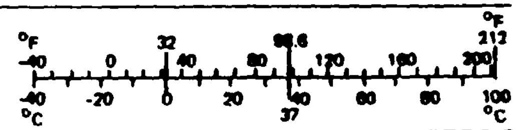
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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13. ABSTRACT (Maximum 200 words)

This report presents three conceptual methods for connecting barge-like modules in open seas. The goal is to identify new technology and materials for use in the development of a high strength connecting system that can be installed fast in open seas with limited heavy lift equipment. The three concepts presented are: (a) flat, flexible connector with pneumatic bladders, (b) cylindrical, flexible connector with pneumatic bladders, and (c) flat, flexible connector with a mechanical closure. Major components of each concept are described to demonstrate the mechanism of the concept. Preliminary calculations are provided to show the strength and holding capacity. The advantages and disadvantages of each concept are discussed. Research and development requirement for each concept are discussed. Research and development requirement for each concept are identified. A test procedure to verify the feasibility of the concepts is also proposed.

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CONCEPTUAL STUDY OF A MODULE CONNECTOR SYSTEM FOR A

DEPLOYABLE WATERFRONT FACILITY (DWF)

(FINAL REPORT)

This study contains three conceptual methods for connecting a series of barge-like modules to provide a floating Deployable Waterfront Facility (DWF) on exposed coastlines. The concepts presented in this report were developed by American Management Systems, Inc. (AMS), Chesapeake, Virginia for the U.S. Department of the Navy, Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California; as required by AMS Contract No. N00123-89-D-0617/EJQE, and as described in NCEL Technical Memorandum M-65-89-08 and its references.

The conceptual methods presented in this study are:

1) Flat Flexible Connector With Pneumatic Bladders

2) Cylindrical Flexible Connector With Pneumatic Bladders

3) Flat Flexible Connector With Mechanical Closure

BACKGROUND:

The mission of the Deployable Waterfront Facility (DWF) is to enhance the Navy's amphibious logistics capability by providing a means for the transfer of containers and rolling stock from commercial and Navy vessels to deployed Marine Corps Amphibious Forces on the beach.

The DWF is a floating platform consisting of a series of barge-like floating modules which can be connected together in various configurations to meet specific mission sites. The DWF is to be moored offshore in water depths up to 150 feet and connected to shore by a floating causeway.

This study focuses on the conceptual development of the connector systems to be used to connect the platform components together.

DESIGN CRITERIA:

The design criteria taken into consideration to develop the concepts presented in this study include the following, as derived from the Statement of Work and the various Technical Memorandums associated with the DWF project.

- DWF shall be capable of operations in Sea State 4 conditions and shall be survivable in Sea State 6.

- Connectors are to be capable of resisting total loads of 1,000 long tons (2,240,000 pounds). It is assumed that 1,000 long tons represent the maximum loads anticipated at the connectors based on DWF survival criteria of Sea State 6.

- Capability of installation in Sea State 2 conditions.

- Connection system to be sufficiently flexible to allow relative motion between barge modules while still allowing vehicle traffic across adjacent modules.

- Barge modules are to have principal dimensions of 300 feet long x 100 feet wide x 25 feet deep, weighing 5,000 long tons each.

- DWF must have the capability of being retrieved and relocated.

DEPLOYABLE WATERFRONT FACILITY (DWF)

CONCEPT NO. 1: *FLAT FLEXIBLE CONNECTOR WITH PNEUMATIC BLADDERS*

DISCUSSION:

This concept consists of a series of flat flexible connectors with integral air bladders or chambers, as illustrated in the Drawing No. I-1 and No. I-2.

These connectors are constructed of a flexible composite material based on a commercially available product having the material specifications and properties as detailed in Appendix A - Table 1.

Air bladders or chambers are encapsulated within the sides of each connector. These air bladders/chambers are each fitted with an air line, molded into the connectors, penetrating their outer ends with quick connect air line fittings.

Separate structurally reinforced receptors are built into the ends and sides of each barge. It is into these receptors that the connectors are inserted.

These receptors are slightly larger than the connectors and their outer upper and lower surfaces are radiused and ramped to assist in the aligning and insertion process. The radiused surfaces at the entrance to the receptors also eliminates sharp edges which would tend to cut into the connector material.

An onboard compressed air system supplies air to a recessed access box built into the deck of the barge at the inboard ends of each receptor.

A work force consisting of several men and a small mobile crane or similar device position individual connectors into these receptors.

Once the connectors are inserted into their receptor, flexible compressed air hoses within these recessed air boxes are connected to the quick connect air line fittings which extend from each connector.

As the air bladders inflates it distorts or conforms the connector material to the interior surfaces of the receptor. The resulting pneumatic force which is created holds the connector in place. There are no mechanical or physical restraints to fail.

The receptors are also designed with recesses along their upper and lower interior surfaces. The connector material will conform into these recesses thus increasing the overall holding capability of each connector.

The cross sectional inverted 'T' shape of each connector acts as a bumper and a spacer between adjacent barges to avoid contact during varying sea and load conditions. The lower end of the inverted 'T' will extend up to and be level with the main deck of the barges to provide a roadway/bridge between adjacent barge modules.

The compressed air piping to each connector is equipped with a series of shut off, dump, and relief valves in order to isolate the air supply to each receptor, if necessary.

All that is necessary to disassemble the DWF, is to dump or relieve the air pressure in the bladders along one side and pull the barge modules apart.

CONNECTOR SIZE AND SHAPE:

For this concept a rectangular shaped connector was evaluated. The rectangular shape of the type illustrated in Drawing No. I-1 and No. I-2, was considered to provide the maximum amount of connector material between adjacent barge modules while maintaining the fewest number of individual components. The fewer the number of connectors which have to be installed equates to less manpower, equipment and time requirements to assemble the DWF.

Based on preliminary calculations, the overall size of each connector is approximately 14 feet long x 14 feet wide x 6 feet deep. The sides, which are inserted into the receptors, are approximately 14 inches deep. Each connector has an estimated weight of approximately 11 long tons.

The integral air bladder/chamber encapsulated within the sides of each connector is approximately 10 feet long x 4 feet wide x 1 inch deep.

To provide an adequate factor of safety and a degree of redundancy, it is recommended that **four** of these style connectors be installed along each side and end of the barge modules to be connected.

CONNECTOR STRENGTH CAPABILITIES:

Preliminary calculations indicate this connector concept has the following strength capabilities.

<u>**Breaking strength**</u>:	4,700,000 lbs. per connector *
Utilizing four connectors:	18,800,000 lbs. total (8,400 long tons)

* Each connector alone is capable of withstanding the maximum total loads anticipated.

Breaking strength is based on the following:

Min. tensile strength of connector material:	2,000 lbs./sq. in.
Connector dimensions:	14' long x 14' wide x 6' deep (14" deep along each side)

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** from tension of **2.1** for each connector and a **Factor of Safety** of **8.4** utilizing a four (4) connector system.

<u>**Pneumatic holding capability**</u>:	1,120,000 lbs. per connector *
Utilizing four connectors:	4,480,000 lbs. total (2,000 long tons)

Holding capability is based on the following:

Proposed air bladder size:	10' long x 4' wide
Proposed air pressure:	162 psi (minimum)
Coefficient of friction:	0.60
Holding capability:	560,000 lbs. per surface
x two surfaces/side	1,120,000 lbs. per connector
Utilizing four connectors	4,480,000 lbs. total (2,000 long tons)

* This does not take into consideration the increase holding capability due to the recesses built into the top and bottom surfaces of each receptor or from any pattern or shape incorporated into these surfaces.

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** based on holding capability of **2.0** utilizing a four (4) connector system.

Shearing Strength: 2,115,000 lbs per connector

Utilizing four connectors:	8,460,000 lbs. total (3,777 long tons)

Shearing strength is based on the following:

Shearing strength of connector material:	900 lbs./sq.in. at maximum elongation
Cross sectional area of connector:	14′ wide x 14" deep = 2,352 sq.in.

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** based on shear of 3.8 utilizing a four (4) connector system.

TECHNOLOGIES:

The following technologies or design aspects will require additional development effort and research.

- **Design characteristics.** A detailed computer analysis of the anticipated loads on the facility will be necessary to fully identify the forces to which the components of this concept will be subjected. Once these forces are known then actual design characteristics and sizing requirements of the individual components can be developed.

- **Connector material.** AMS has had preliminary discussions with a manufacturer of the material discussed above. Although this material is presently not being used in an application similar to the proposed use, the material specifications and properties made available indicate that this material, or a material with similar characteristics, should be suitable.

  Part of the development of actual design characteristics for the connectors will include an examination into material modification or adaptation. To increase the strength of the connectors it may be necessary to incorporate additional strength members into the material. This may include the introduction of steel belts, similar to those found in radial tires, which will add strength yet still permit the connectors the flexibility required. It may also include the introduction of heavy structural strength members to minimize sagging during installation. These consideration will require direct input by a manufacturer, ie. Goodyear Tire and Rubber Company, to study the feasibility of this type of modifications and the problems which may be associated with it.

- **Air bladder.** The design and material specifications for the internal air bladder has to be further investigated and developed.

  There are several air bladder applications presently in use which should meet the requirements of this concept. These include application in the suspension systems for buses and trucks. The manufacturers we contacted considered the information pertaining to their air bladder systems as proprietary and were reluctant to provide strength properties and material characteristics at this time. However, it is our opinion that presently available air bladder technology could be easily modified for use as proposed in this concept considering the similarity of operating air pressures.

  Additional design and research efforts on the air bladder will focus on how best to encapsulate this bladder within a chamber internal to the connector to assure the integrity of the bladder. Preliminary calculations indicate that there could be as much as 7 inches of connector material surrounding the air bladder/chamber.

  Further analysis will also be required to determine how much deformation of the connector above and below the bladder can be expected given the proposed air pressure. Modifications to the design may be necessary based on the outcome of this analysis.

- **Receptors.** Structural design analysis will be required to develop a receptor and surrounding structure with sufficient strength to withstand the anticipated loads. Structural design of the receptor will be dependent upon final system requirements.

  If it is decided to provide the capability of removing and replacing a connector while the facility is still coupled together than the receptors will have to be built in two pieces where the top half can be unbolted and removed to provide access to the connector.

  Further analysis will also be required to determine the best type of material from which to construct the receptors, the size and shape of the recessed areas or pattern to be incorporated into the upper and lower surfaces of the receptors, and the design of the entrance openings.

- **Compressed air system.** Compressed air requirements for this concept will include a standard diesel driven air compressor with an air receiver and a fuel oil system. A dedicated air system could be installed on each barge module or if the module is already equipped with air capability then the air resources could be shared, reducing the need for additional equipment and the maintenance associated with it.

As presently conceived, each bladder when inflated would require approximately 5 cu ft of air at the proposed minimum 162 psi air pressure. Air would enter the bladder via a non-return check valve and would be released via a separate connection.
The design of the bladder is such that there is no need for a continuous flow of air, once inflated the compressor would shut down. The air receiver would make up for any leakage which did occur. Maintenance on this compressed air system would be the same as for any diesel driven compressed air system.

ADVANTAGES:

The advantages of this concept are as follows:

- **Strength/Flexibility of material.** The strength of the connector material will allow it to withstand the extreme forces and loads anticipated; yet is flexible enough to allow for relative motion between barge modules, more so than a rigid connector.

- **Holding capability.** Utilizing the proposed minimum air pressure of 162 psi in the air bladders, each connector is capable of resisting a pull of 1,120,000 lbs. The air pressure to the air bladders could easily be increased resulting in a correspondingly higher holding capability.

- **Redundancy.** It is proposed to utilize four rectangular connectors along each side and end of the barge modules to be connected. As calculated, if one of the connectors along the face or end of a barge module were to fail, the remaining three would still be able to withstand the total anticipated loads.

- **Ease of installation.** It is envisioned that the actual connection of individual barge modules would take place on the leeward side of the heavy lift vessel which transports the modules to the site where the facility will be deployed. Working on the leeward side of the vessel would afford a degree of protection as well as assist in aligning the initial barge modules together.

All connectors along the end or sides of one of the barge modules are inserted into individual receptors. This will require the use of a small mobile crane or similar device and several men to assist in handling each receptor. Air supply lines are connected to each bladder, the air bladders are charged, and these connectors are held in place.

Once the connectors along one face of a barge are in place, a second barge is floated into position and the connectors are slipped into mating receptors. This mating process will probably also require the use of small mobile cranes and man power to assure proper alignment. Air lines are connected to the air bladders along the side of the second barge, these air bladders are charged, and the installation is complete. There is no need for heavy equipment, chains, mooring lines, or complicated devices to make the connections.

To break the connection, simply dump or relieve the air pressure to the appropriate connectors and pull the barge modules apart.

The most difficult part of assembling this facility will be the alignment of adjacent barge modules. As presented, this concept requires that connectors be inserted into one barge module before the adjacent module is floated into position. Since this concept proposes the use of only four connectors, the actual alignment and insertion process is simplified. The more connectors which are used the more difficult the insertion process becomes and the more manpower and equipment that will be necessary.

- **Functions as a bumper.** The use of a rubber type material for the connectors eliminates the need for any other type of fendering or bumper material between barges. The greater the depth of the inverted 'T' shape of each connector the more protection is provided between adjacent barge modules.

  In addition to functioning as a fender once the barge modules are connected, these connectors will also function as a fender to minimize contact between barge modules during the time that the facility is being assembled.

- **Functions as a roadway.** The size, shape, and strength of the connector material considered will allow mobile equipment to transit from one barge to another; without the need of installing, securing, or maintaining any additional bridging or roadway systems.

- **Minimal maintenance requirements.** Once in place, the connectors will require minimal maintenance. Periodic servicing of the primary air system machinery will be necessary, however, it will be minimal since the air bladders will not require a constant supply of air.

DISADVANTAGES:

The disadvantages of this concept are as follows:

- **Failure due to shear.** If the connector fails due to shear this will most probably occur at the point just inboard of where the connector enters the receptor, in way of the outboard end of the air bladder/chamber; indicated as Dimension 'T3' on Drawing I-2. It is at this point where the depth of the connector is the smallest and is considered to be a critical dimension.

  Further design and analysis will be necessary to determine the precise thickness across this location and to determine if the material needs to be reinforced, especially in the area indicated above, to increase its ability to resist the anticipated shearing loads.

- **Failure of a connector or air bladder.** If a connector or an air bladder, as presented in this concept, were to fail, the failed connector could not be replaced without separating or disconnecting part of the DWF, due to the manner of initial connector installation.

  The ultimate selection on the number of connectors to be used to connect the DWF together will include a consideration of the desired factor of safety and redundancy. As presented, there is redundancy built into the system, such that the failure of any one connector will not adversely impact the ability of the remaining connectors to maintain the integrity of the facility.

  If the redundancy of several connectors is considered insufficient to meet design characteristics for the facility, the receptors could be modified to allow for connector replacement without separating adjacent barge modules. Bolted cover plates could replace the deck plates above each receptor and the receptors could be split into two halves bolted together around their perimeter. These cover plates and the receptors would normally remain bolted together at all times and the connectors would still be inserted as discussed earlier. These bolted covers would only be used in an emergency and when an individual connector had to be replaced after the facility was assembled.

- **Maintenance of the Receptors.** An excessive amount of oil or grease within the receptors prior to connector insertion or the entry of oil and grease after the connectors are in place could be detrimental to that connector's holding capability.

It would be the responsibility of operating personnel to insure that the receptors are free of all grease and oil prior to inserting the connectors. If deemed necessary a simple cover plate could be built which would close or seal each receptor while the barge modules are in transit or when a receptor is not in use to minimize the entry of any debris. Drains incorporated at the inboard ends of each receptor would prevent the accumulation of any water.

ADDITIONAL CONSIDERATIONS:

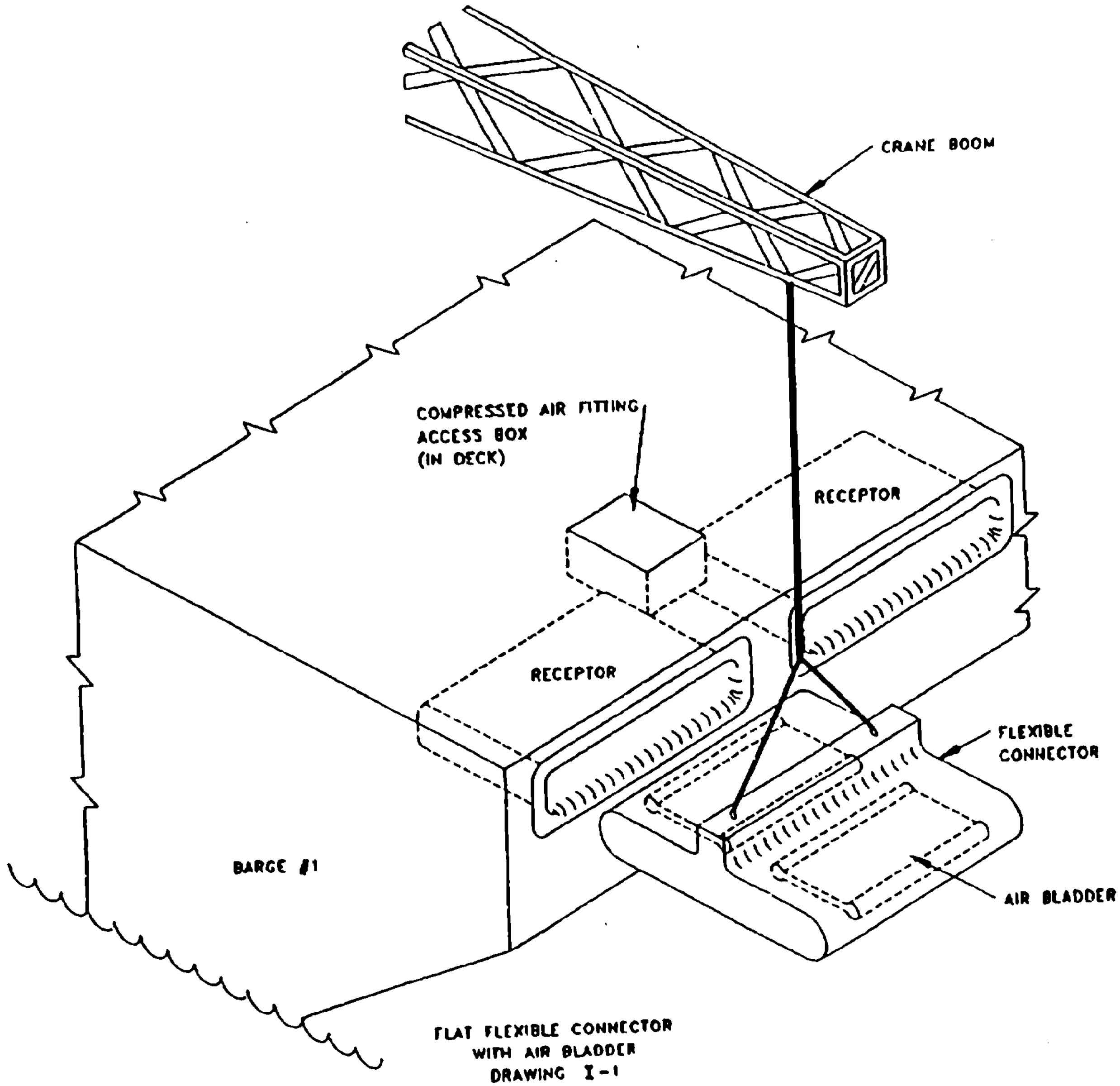
The following is a listing of several areas which require additional consideration and evaluation as development of this concept continues.

- Consider the use of a cruciform shape versus an inverted 'T' shape for the connectors. This would allow for a better distribution of loads and provide additional fendering between adjacent barge modules.

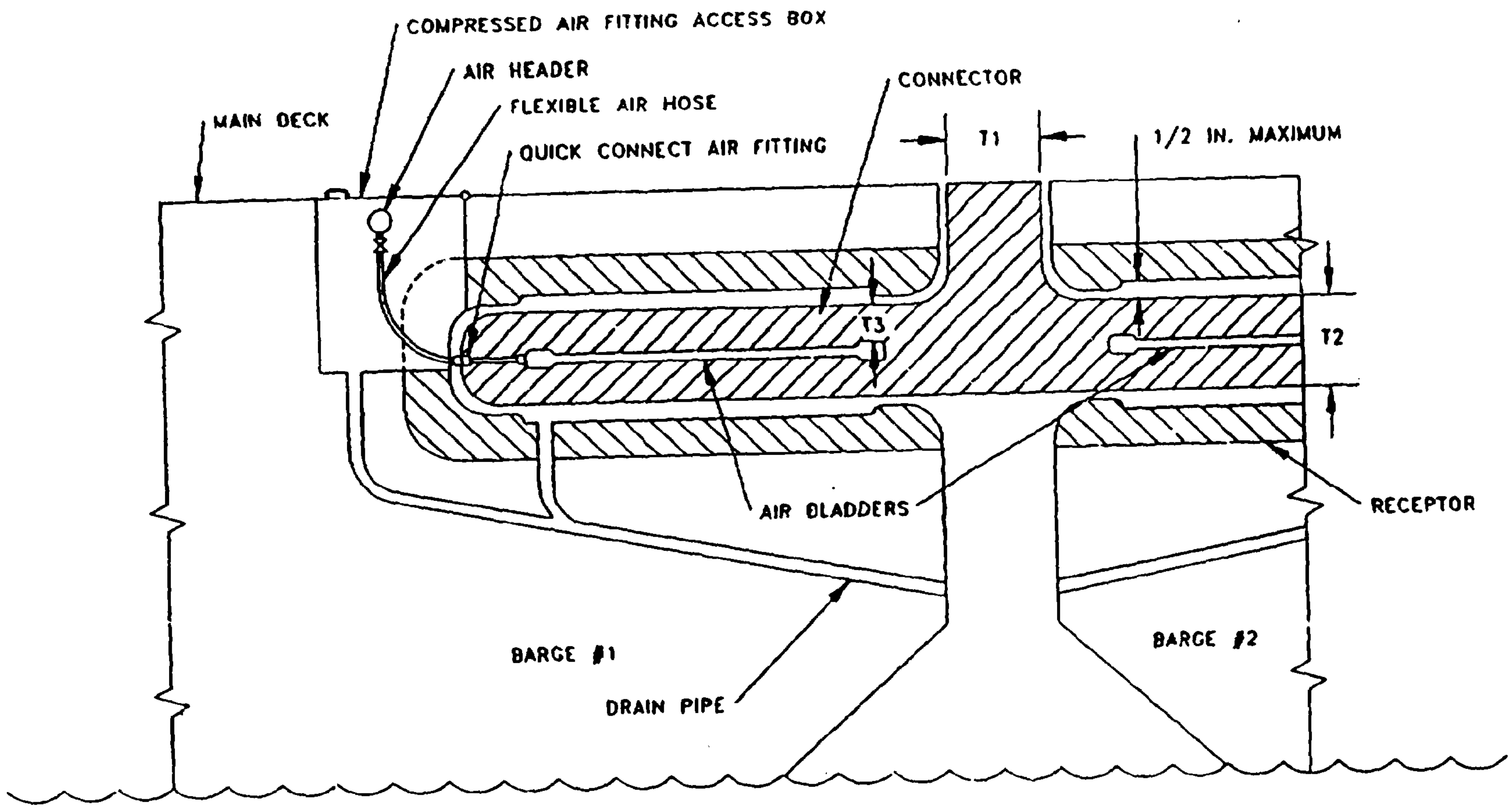
- Consider multiple air bladders/chambers within the sides of each connector. This would provide additional redundancy across each connector. The failure of a single bladder per connector system would render that connector useless. A multiple bladder system could be designed so that failure of a single bladder in a connector would result in a corresponding increase in air pressure to the remaining bladders of that connector. Thus maintaining the overall holding capability of that connector.

- This concept currently includes the use of a separate air bladder, located within a chamber incorporated into each connector. Additional analysis will be necessary to determine if a separate air bladder is essential. It may be possible to achieve the desired results by simply charging the chamber with air, eliminating the need for a separate bladder and the problems associated with encapsulating it within the connector.

- The incorporation of a built up pattern, similar to the a 'diamond thread pattern' found on deck plates, into the interior surfaces of the receptor would provide a multitude of additional surfaces around which the connector material could conform after it is inflated, further increasing its holding capability.



FLAT FLEXIBLE CONNECTOR
WITH AIR BLADDER
DRAWING I-1



CROSS SECTION OF
FLAT FLEXIBLE CONNECTOR
DRAWING I-2

DEPLOYABLE WATERFRONT FACILITY (DWF)

CONCEPT NO. 2: *CYLINDRICAL FLEXIBLE CONNECTOR WITH PNEUMATIC BLADDERS*

DISCUSSION:

This concept consists of a series of cylindrical flexible connectors with integral air bladders or chambers, as illustrated in the Drawing No. II-1 and No. II-2.

These connectors are constructed of a flexible composite material based on a commercially available product having the material specifications and properties as detailed in Appendix A - Table 1.

Air bladders or chambers are encapsulated within the sides of each connector. These air bladders/chambers are each fitted with an air line, molded into the connectors, penetrating their outer ends with quick connect air line fittings.

Separate structurally reinforced receptors are built into the ends and sides of each barge. It is into these receptors that the connectors are inserted.

These receptors are slightly larger than the connectors and their outer edges are radiused and ramped to assist in the aligning and insertion process. The radiused edges at the entrance to the receptors also eliminates sharp edges which would tend to cut into the connector material.

An onboard compressed air system supplies air to a recessed access box built into the deck of the barge at the inboard ends of each receptor.

A work force consisting of several men and a small mobile crane or similar device position individual connectors into these receptors.

Once the connectors are inserted into their receptor, flexible compressed air hoses within these recessed air boxes are connected to the quick connect air line fittings which extend from each connector.

As the air bladders inflates it distorts or conforms the connector material to the interior surfaces of the receptor. The resulting pneumatic force which is created holds the connector in place. There are no mechanical or physical restraints to fail.

The receptors are also designed with recesses built into their interior circumferential surfaces. The connector material will conform into these recesses thus increasing the overall holding capability of each connector.

The design of these connectors incorporates a flat rectangular section of material midway along the length of the cylindrical portion of the connector. This rectangular section is either molded together with the cylindrical portion of the connector or is manufactured as a separate component, through which the cylindrical connector is positioned. This rectangular section acts as a bumper and a spacer between adjacent barges to avoid contact during varying sea and load conditions. The upper portion of this rectangular section of the connector extends up to and is level with the main deck of the barges to provide a roadway or bridge between adjacent barge modules.

The compressed air piping to each connector is equipped with a series of shut off, dump, and relief valves in order to isolate the air supply to each receptor, if necessary.

All that is necessary to disassemble the DWF, is to dump or relieve the air pressure in the bladders along one side and pull the barge modules apart.

CONNECTOR SIZE AND SHAPE:

For this concept a cylindrical shaped connector was evaluated. The cylindrical shape of the type illustrated in Drawing No. II-1 and No. II-2, was considered to provide a smaller and perhaps easier to handle connector. The cylindrical shape also meant that more connectors could be positioned along each side and end of the barge modules thus allowing for a greater amount of redundancy. Conversely, the more connectors means the more manpower, equipment and time that would be required to assemble the DWF.

Based on preliminary calculations, the cylindrical portion of each connector is approximately 4 feet in diameter x 20 feet long. The rectangular section of the connector is approximately 8 feet long x 8 feet wide x 2 feet thick. Each connector has an estimated weight of approximately 11 long tons.

The integral air bladder/chamber encapsulated within the ends of the cylindrical portion of each connector is approximately 40 inches in diameter x 8 feet long x 1 inch thick.

To provide an adequate factor of safety and a degree of redundancy, it is recommended that eight of these style connectors be installed along each side and end of the barge modules to be connected.

CONNECTOR STRENGTH CAPABILITIES:

Preliminary calculations indicate this connector concept has the following strength capabilities.

Breaking strength	3,600,000 lbs. per connector *
Utilizing eight connectors:	28,800,000 lbs. total (12,850 long tons)

* Each connector alone is capable of withstanding the maximum total loads anticipated.

Breaking strength is based on the following:

Min. tensile strength of connector material:	2,000 lbs./sq. in.
Connector dimensions:	4' diameter x 20' long

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** from tension of **1.4** for each connector and a **Factor of Safety** of **12.8**, utilizing an eight (8) connector system.

Pneumatic holding capability:	560,000 lbs. per connector *
Utilizing eight connectors:	4,480,000 lbs. total (2,000 long tons)

Based on the following:

Proposed air bladder size:	4' diameter x 8' long
Proposed air pressure:	156 psi (minimum)
Coefficient of friction:	0.6
Holding capability:	560,000 lbs. per connector
Utilizing eight connectors	4,480,000 lbs. total

* This does not take into consideration the increase holding capability due to the recess built into the circumference of the each receptor.

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** based on holding capability of **2.0** utilizing an eight (8) connector system.

Shearing Strength:	1,620,000 lbs per connector
Utilizing eight connectors:	12,960,000 lbs. total (5,786 long tons)

Shearing strength is based on the following:

Shearing strength of connector material:	900 lbs./sq.in. at maximum elongation
Cross sectional area of connector:	4' diameter shape = 1800 sq.in.

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** based on shear of 5.8 utilizing an eight (8) connector system.

TECHNOLOGIES:

The following technologies or design aspects will require additional development effort and research.

- **Design characteristics.** A detailed computer analysis of the anticipated loads on the facility will be necessary to fully identify the forces to which the components of this concept will be subjected. Once these forces are known then actual design characteristics and sizing requirements of the individual components can be developed.

- **Connector material.** AMS has had preliminary discussions with a manufacturer of the material discussed above. Although this material is presently not being used in an application similar to the proposed use, the material specifications and properties made available indicate that this material, or a material with similar characteristics, should be suitable.

  Part of the development of actual design characteristics for the connectors will include an examination into material modification or adaptation. To increase the strength of the connectors it may be necessary to incorporate additional strength members into the material. This may include the introduction of steel belts, similar to those found in radial tires, which will add strength yet still permit the connectors the flexibility required. It may also include the introduction of heavy structural strength members to minimize sagging during installation. These consideration will require direct input by a manufacturer, ie. Goodyear Tire and Rubber Company, to study the feasibility of this type of modifications and the problems which may be associated with it.

- **Air bladder.** The design and material specifications for the internal air bladder has to be further investigated and developed.

  There are several air bladder applications presently in use which should meet the requirements of this concept. These include application in the suspension systems for buses and trucks. The manufacturers we contacted considered the information pertaining to their air bladder systems as proprietary and were reluctant to provide strength properties and material characteristics at this time. However, it is our opinion that presently available air bladder technology could be easily modified for use as proposed in this concept considering the similarity of operating air pressures.

  Additional design and research efforts on the air bladder will focus on how best to encapsulate this bladder within a chamber internal to the connector to assure the integrity of the bladder.

  With this concept, the air bladder can be physically located relatively close to the outer circumference of the connector, since all the holding capability is directed outward toward the wall of the receptor. The closer the bladder can be located toward the outer surface of the connector, the lesser amount of connector material which will have to be distorted to obtain the desired holding force.

  Further analysis will be required to determine exactly how much deformation of the connector can be expected at the proposed air pressure. Modifications to the design may be necessary based on the outcome of this analysis.

- **Receptors.** Structural design analysis will be required to develop a receptor and surrounding structure with sufficient strength to withstand the anticipated loads. Structural design of the receptor will be dependent upon final system requirements. Considering the cylindrical shape of the this connector, the receptor would be made from pipe with suitable structural support between it and the surrounding structure of the barge.

  If it is decided to provide the capability of removing and replacing a connector while the facility is still coupled together than the receptors will have to be built in two pieces where the top half can be unbolted and removed to provide access to the connector.

Further analysis will also be required to determine the best type of material from which to construct the receptors, the size and shape of the recessed areas or pattern to be incorporated into the inner surfaces of the receptors, and the design of the entrance openings.

- **Compressed air system.** Compressed air requirements for this concept will include a standard diesel driven air compressor with an air receiver and a fuel oil system. A dedicated air system could be installed on each barge module or if the module is already equipped with air capability then the air resources could be shared, reducing the need for additional equipment and the maintenance associated with it.

  As presently conceived, each bladder when inflated would require approximately 3.5 cu ft of air at the proposed minimum 156 psi air pressure. Air would enter the bladder via a non-return check valve and would be released via a separate connection.

  The design of the bladder is such that there is no need for a continuous flow of air, once inflated the compressor would shut down. The air receiver would make up for any leakage which did occur. Maintenance on this compressed air system would be the same as for any diesel driven compressed air system.

ADVANTAGES:

The advantages of this concept are as follows:

- **Strength/Flexibility of material.** The strength of the connector material will allow it to withstand the extreme forces and loads anticipated; yet is flexible enough to allow for relative motion between barge modules, more so than a rigid connector.

- **Holding capability.** Utilizing the proposed minimum air pressure of 156 psi in the air bladders of these connectors, each connector is capable of resisting a lineal pull of 560,000 lbs. The air pressure to the air bladders could easily be increased resulting in a correspondingly higher holding capability.

- **Redundancy.** It is proposed to utilize eight cylindrical connectors along each side and end of the barge modules to be connected. As calculated, four of the connectors along the face or end of a barge module could fail and the remaining four would still be able to withstand the total anticipated loads.

- **Ease of installation.** It is envisioned that the actual connection of individual barge modules would take place on the leeward side of the heavy lift vessel which transports the modules to the site where the facility will be deployed. Working on the leeward side of the vessel would afford a degree of protection as well as assist in aligning the initial barge modules together.

  All connectors along the end or sides of one of the barge modules are inserted into individual receptors. This will require the use of a small mobile crane or similar device and several men to assist in handling each receptor. Air supply lines are connected to each bladder, the air bladders are charged, and these connectors are held in place.

  Once the connectors along one face of a barge are in place, a second barge is floated into position and the connectors are slipped into mating receptors. This mating process will probably also require the use of small mobile cranes and man power to assure proper alignment. Air lines are connected to the air bladders along the side of the second barge, these air bladders are charged, and the installation is complete. There is no need for heavy equipment, chains, mooring lines, or complicated devices to make the connections.

  To break the connection, simply dump or relieve the air pressure to the appropriate connectors and pull the barge modules apart.

  The most difficult part of assembling this facility will be the alignment of adjacent barge modules. As presented, this concept requires that connectors be inserted into one barge module before the adjacent module is floated into position. Since this concept proposes the use of eight connectors, the insertion process will require precise alignment and coordination to made the actual connection.

- **Functions as a bumper.** The use of a rubber type material for the connectors eliminates the need for any other type of fendering or bumper material between barges. The greater the depth of the inverted 'T' shape of each connector the more protection is provided between adjacent barge modules.

  In addition to functioning as a fender once the barge modules are connected, these connectors will also function as a fender to minimize contact between barge modules during the time that the facility is being assembled.

- **Functions as a roadway.** The size, shape, and strength of the connector material considered will allow mobile equipment to transit from one barge to another; without the need of installing, securing, or maintaining any additional bridging or roadway systems.

- **Minimal maintenance requirements.** Once in place, the connectors will require minimal maintenance. Periodic servicing of the primary air system machinery will be necessary, however, it will be minimal since the air bladders will not require a constant supply of air.

DISADVANTAGES:

The disadvantages of this concept are as follows:

- **Failure due to shear.** If the connector fails due to shear this will most probably occur at the point just inboard of where the connector enters the receptor, in way of the outboard end of the air bladder/chamber. It is at this point where the depth of the connector is the smallest and is considered to be a critical dimension.

  Further design and analysis will be necessary to determine the precise thickness across this location and to determine if the material needs to be reinforced, especially in the area indicated above, to increase its ability to resist the anticipated shearing loads. During this analysis it will also be determined exactly how far inboard from the outer surface of the connector that the air bladder can be located.

- **Failure of a connector or air bladder.** If a connector or an air bladder, as presented in this concept, were to fail, the failed connector could not be replaced without separating or disconnecting part of the DWF, due to the manner of initial connector installation.

  The ultimate selection on the number of connectors to be used to connect the DWF together will include a consideration of the desired factor of safety and redundancy. As presented, there is redundancy built into the system, such that the failure of any one or several of these connectors will not adversely impact the ability of the remaining connectors to maintain the integrity of the facility.

  If the redundancy of several connectors is considered insufficient to meet design characteristics for the facility, the receptors could be modified to allow for connector replacement without separating adjacent barge modules. Bolted cover plates could replace the deck plates above each receptor and the receptors could be split into two halves bolted together around their perimeter. These cover plates and the receptors would normally remain bolted together at all times and the connectors would still be inserted as discussed earlier. These bolted covers would only be used in an emergency and when an individual connector had to be replaced after the facility was assembled.

ADDITIONAL CONSIDERATIONS:

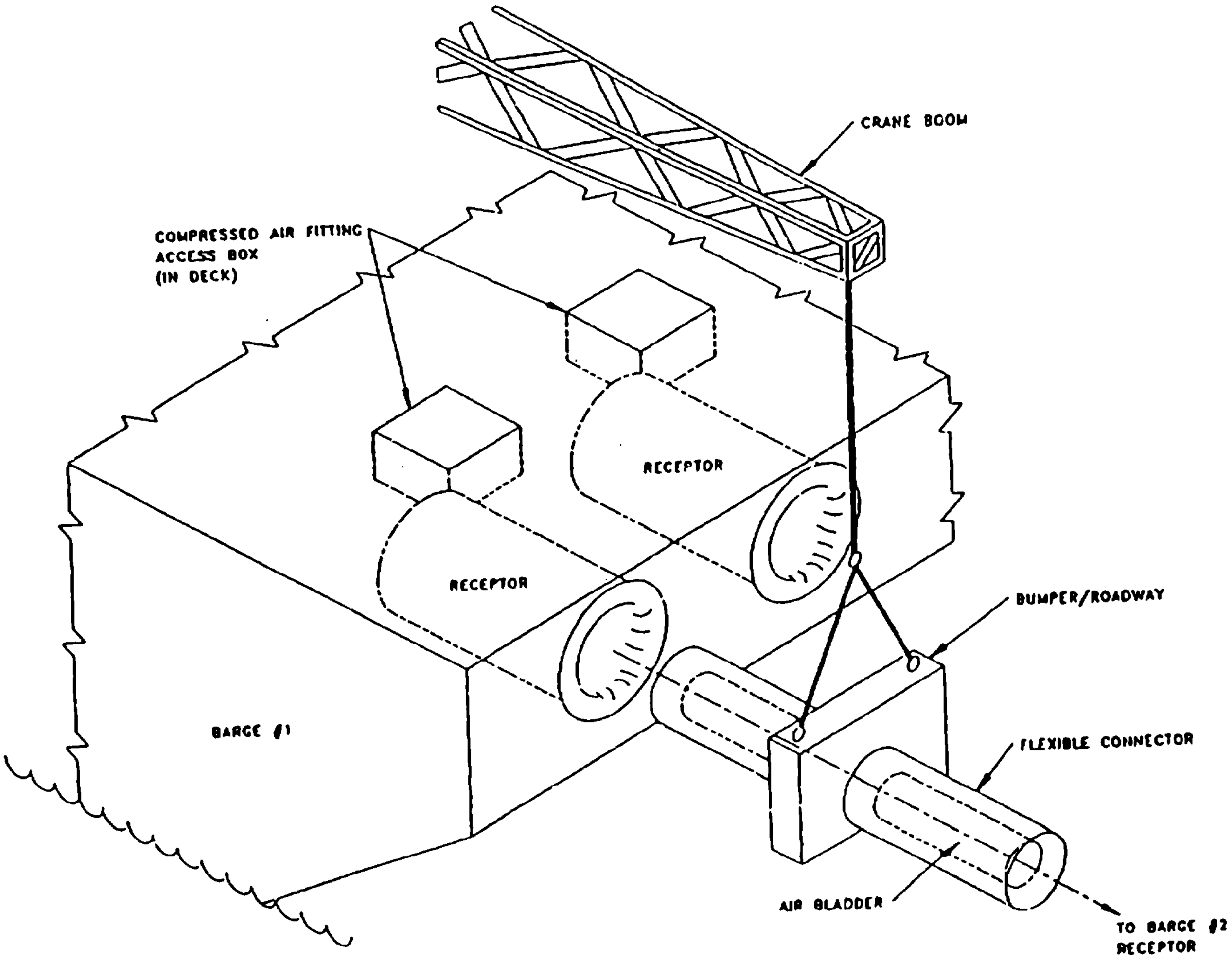
The following is a listing of several areas which require additional consideration and evaluation as development of this concept continues.

- The rectangular portion of the connector which acts as a fender or bumper can be sized to allow for better distribution of loads across the mating surfaces of the adjacent barge modules and to provide additional fendering.

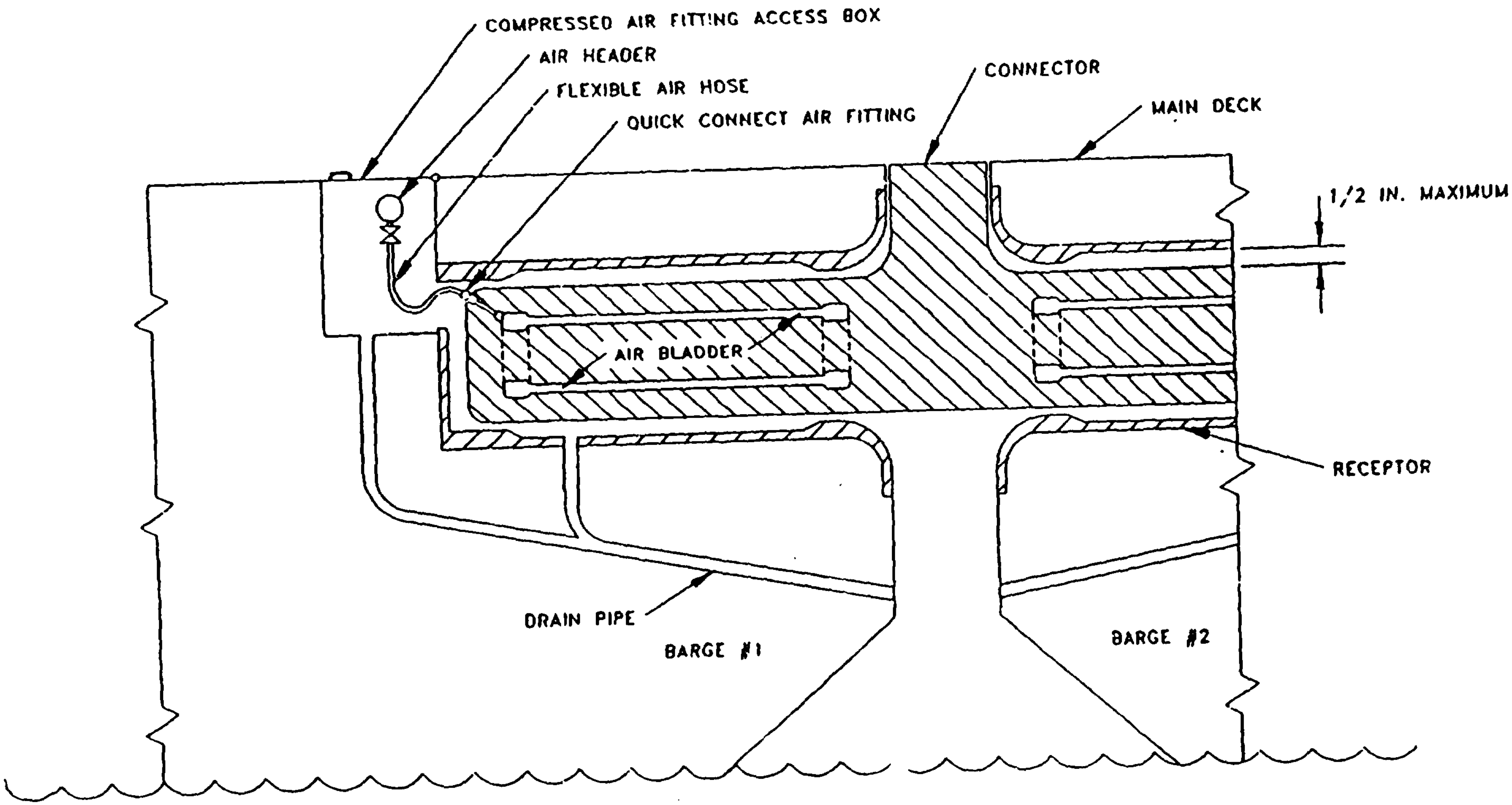
- Multiple air bladders/chambers within the sides of each connector would provide additional redundancy for each connector. The failure of a single bladder per connector system would render that connector useless. A multiple bladder system could be designed so that failure of a single bladder in a connector would result in a corresponding increase in air pressure to the remaining bladders of that connector. Thus maintaining the overall holding capability of that connector.

- This concept currently includes the use of a separate air bladder, located within a chamber incorporated into each connector. Additional analysis will be necessary to determine if a separate air bladder is essential. It may be possible to achieve the desired results by simply charging the chamber with air, eliminating the need for a separate bladder and the problems associated with encapsulating it within the connector.

- The incorporation of a built up pattern, similar to the a 'diamond thread pattern' found on deck plates, into the interior surfaces of the receptor would provide a multitude of additional surfaces around which the connector material could conform after it is inflated, further increasing its holding capability.



CYLINDRICAL FLEXIBLE CONNECTOR
WITH AIR BLADDER
DRAWING II-1



CROSS SECTION OF
CYLINDRICAL FLEXIBLE CONNECTOR
DRAWING II-2

DEPLOYABLE WATERFRONT FACILITY (DWF)

CONCEPT NO. 3: *FLAT FLEXIBLE CONNECTOR WITH MECHANICAL CLOSURE*

DISCUSSION:

This concept consists of a series of flat flexible connectors which are held in place with a mechanical mechanism, as illustrated in the Drawing No. III-1 and No. III-2.

These connectors are constructed of a flexible composite material based on a commercially available product having the material specifications and properties as detailed in Appendix A - Table 1.

Structurally reinforced receptors are built into the ends and sides of each barge. The top of each receptor, which is part of the main deck, is hinged and acts as a closure plate for that receptor. Then the DWF is to be assembled, the closure plates along the ends of the barges to be connected are raised, using the double acting air cylinders and connecting rods, attached to the outboard ends of each closure plate. Flexible inverted 'T' shaped connectors are positioned into individual receptors. The closure plate is closed, the connector material is compressed, and the connector is held in place within its receptor.

To assist in holding the connectors in place, the upper and lower surfaces of each connector where they fit into the receptors incorporate a shape or 'saw tooth' type pattern. This shape or pattern will extending transversely across the surface of the connectors, relative to the axis of the barge. The corresponding surfaces of the receptors will be constructed with a similar but reversed shape, so when the receptor closure plates are secured, these areas will lock together to assist in holding them in place.

The outboard ends of the receptors are radiused to avoid sharp edges which would tend to cut into the connector material.

The cross sectional inverted 'T' shape of each connector acts as a bumper and a spacer between adjacent barges to avoid contact during varying sea and load conditions. The lower end of the inverted 'T' will extend up to and be level with the main deck of the barges to provide a roadway/bridge between adjacent barge modules.

To disassemble the DWF, the closure plates along the side of the facility to be disconnected, are raised and the barge modules are pulled apart. Either the connectors are left in place in one or other receptors or they are removed and stowed on deck.

CONNECTOR SIZE AND SHAPE:

For this concept a rectangular shaped connector was evaluated. The rectangular shape of the type illustrated in Drawing No. III-1 and No. III-2, was considered to provide the maximum amount of connector material between adjacent barge modules while maintaining the fewest number of individual components. The fewer the number of connectors which have to be installed equates to less manpower, equipment and time requirements to assemble the DWF.

Based on preliminary calculations, the overall size of each connector is approximately 14 feet long x 14 feet wide x 6 feet deep. The sides, which are inserted into the receptors, are approximately 14 inches deep. Each connector has an estimated weight of approximately 11 long tons.

To provide an adequate factor of safety and a degree of redundancy, it is recommended that four of these style connectors be installed along each side and end of the barge modules to be connected.

CONNECTOR STRENGTH CAPABILITIES:

Preliminary calculations indicate this connector concept has the following strength capabilities.

Breaking strength:	4,700,000 lbs. per connector *
Utilizing four connectors:	18,800,000 lbs. total (8,400 long tons)

* Strength of each connector provided the closure plates and locking mechanism can be designed to adequately resist the forces imparted to the connector. Additional study will be necessary to further analysis this aspect of this concept.

Breaking strength is based on the following:

Min. tensile strength of connector material:	2,000 lbs./sq. in.
Connector dimensions:	14' long x 14' wide x 6' deep (14" deep along each side)

* This does not take into consideration the increase holding capability due to the depressions built into the top and bottom surfaces of each connector.

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** from tension of **2.1** for each connector and a **Factor of Safety** of **8.4** utilizing a four (4) connector system.

Shearing Strength:	2,115,000 lbs per connector
Utilizing four connectors:	8,460,000 lbs. total (3,777 long tons)

Shearing strength is based on the following:

Shearing strength of connector material:	900 lbs./sq.in. at maximum elongation
Cross sectional area of connector:	14′ wide x 14" deep = 2,352 sq.in.

Considering an anticipated maximum total load of 1,000 long tons (2,240,000 lbs.), this concept results in a **Factor of Safety** based on shear of **3.8** utilizing a four (4) connector system.

TECHNOLOGIES:

The following technologies or design aspects will require additional development effort and research.

- **Design characteristics.** A detailed computer analysis of the anticipated loads on the facility will be necessary to fully identify the forces to which the components of this concept will be subjected. Once these forces are known then actual design characteristics and sizing requirements of the individual components can be developed.

- **Connector material.** AMS has had preliminary discussions with a manufacturer of the material discussed above. Although this material is presently not being used in an application similar to the proposed use, the material specifications and properties made available indicate that this material, or a material with similar characteristics, should be suitable.

Part of the development of actual design characteristics for the connectors will include an examination into material modification or adaptation. To increase the strength of the connectors it may be necessary to incorporate additional strength members into the material. This may include the introduction of steel belts, similar to those found in radial tires, which will add strength yet still permit the connectors the flexibility required. It may also include the introduction of heavy structural strength members to minimize sagging during installation. These consideration will require direct input by a manufacturer, ie. Goodyear Tire and Rubber Company, to study the feasibility of this type of modifications and the problems which may be associated with it.

Additional consideration will be necessary whether to include a 'saw tooth' type pattern into the connector with a reverse shaped pattern on the surfaces of the receptor or to form the connector into a wedge. Either case will increase the holding capability of the assembled unit.

- **Receptors.** Structural design analysis will be required to develop a receptor, closure plate, and surrounding structure with sufficient strength to withstand the anticipated loads. Structural design of the receptor will be dependent upon final system requirements.

  Further analysis will also be required to determine the best type of material from which to construct the receptors, the size and shape of the pattern to incorporated into the connectors and the upper and lower surfaces of the receptors.

ADVANTAGES:

The advantages of this concept are as follows:

- **Strength/Flexibility of material.** The strength of the connector material will allow it to withstand the extreme forces and loads anticipated; yet is flexible enough to allow for relative motion between barges, more so than a rigid connector.

- **Redundancy.** It is proposed to utilize four rectangular connectors along each side and end of the barge modules to be connected. As calculated, if one of the connectors along the face or end of a barge module were to fail, the remaining three would still be able to withstand the total anticipated loads.

- **Ease of installation.** It is envisioned that the actual connection of individual barge modules would take place on the leeward side of the heavy lift vessel which transports the modules to the site where the facility will be deployed.

Working on the leeward side of the vessel would afford a degree of protection as well as assist in aligning the initial barge modules together.

Receptor closure plates are raised along the end of one barge module and a connector is positioned into each receptor using a small mobile crane or similar device and several men to assist in handling each receptor. After the connector is installed, the closure plate is lowered and secured, and the connector is locked in place. Once the connectors along one end of a barge module are in place, the closure plates on a second barge module are raised, the module is floated into position, the connectors are slipped into mating receptors, the closure plates are lowered and secured. There is no need for heavy equipment, chains, mooring lines, or complicated devices to make the connections.

The task of connecting the facility together utilizing this concept is somewhat simplified since the opening of the closure plates provides ample room for aligning and adjusting the connectors during the mating process.

To break the connection, simply raise the closure plates to the appropriate connectors and pull the barge modules apart.

- **Functions as a bumper.** The use of a rubber type material for the connectors eliminates the need for any other type of fendering or bumper material between barges. The greater the depth of the inverted 'T' shape of each connector the more protection is provided between adjacent barge modules.

  In addition to functioning as a fender once the barge modules are connected, these connectors will also function as a fender to minimize contact between barge modules during the time that the facility is being assembled.

- **Functions as a roadway.** The size, shape, and strength of the connector material considered will allow mobile equipment to transit from one barge to another; without the need of installing, securing, or maintaining any additional bridging or roadway systems.

- **Minimal connector maintenance.** Once in place, the connectors themselves will require minimal maintenance.

- **Connector change out.** Since the receptors in the concept are equipped with hinged closure plates, it permits the removal and replacement of individual connectors without disrupting or separating the DWF.

DISADVANTAGES:

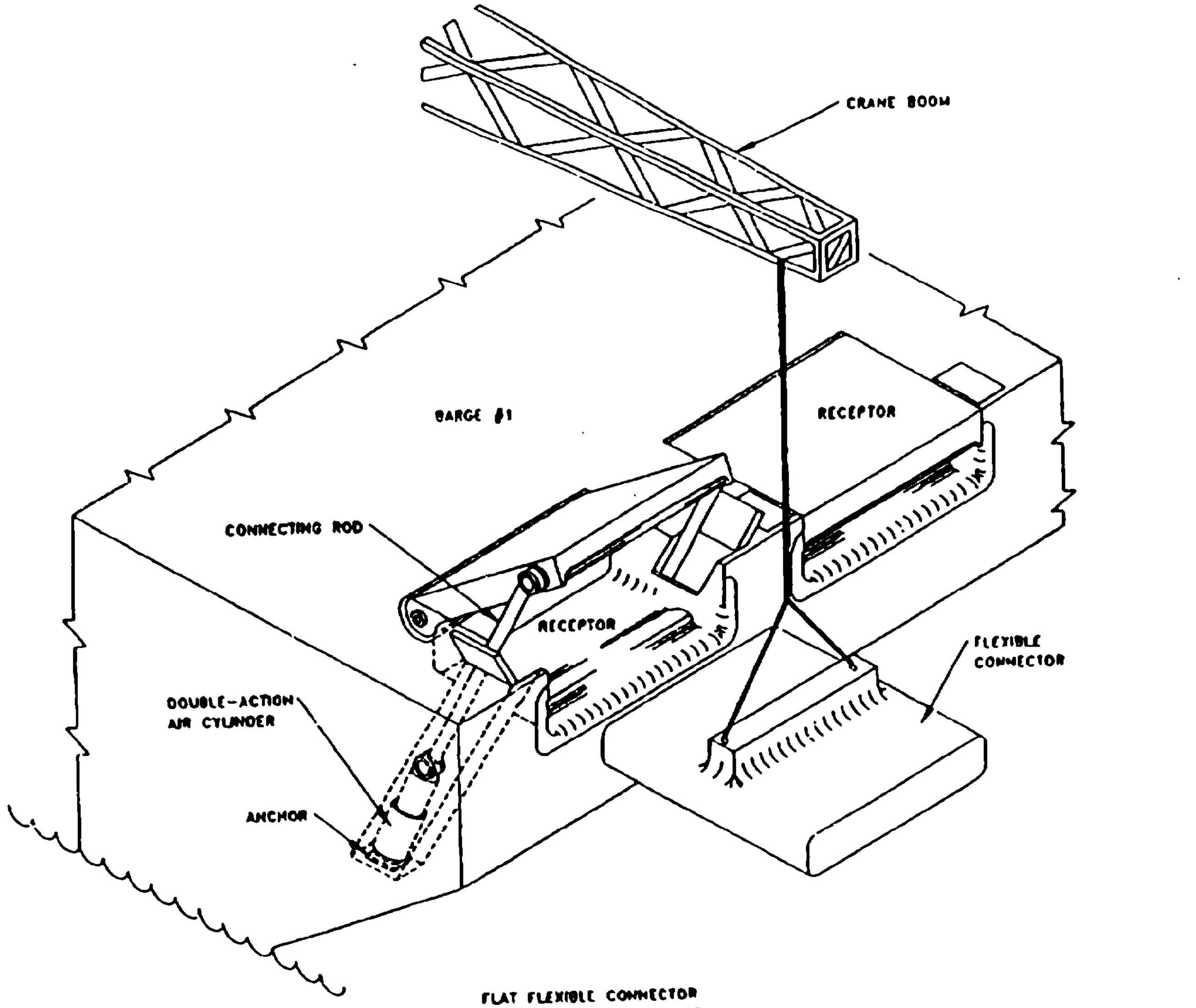
The disadvantages of this concept are as follows:

- **Closure Plate Maintenance.** This concept will require that periodic maintenance be performed on the various components of the closure plate device. Prior to the insertion of a connector the closure plates will have to be operated to prove they are functioning properly. Closure plate air cylinders and hinge pins will require periodic inspection and lubrication. The compressed air system will also require periodic servicing.

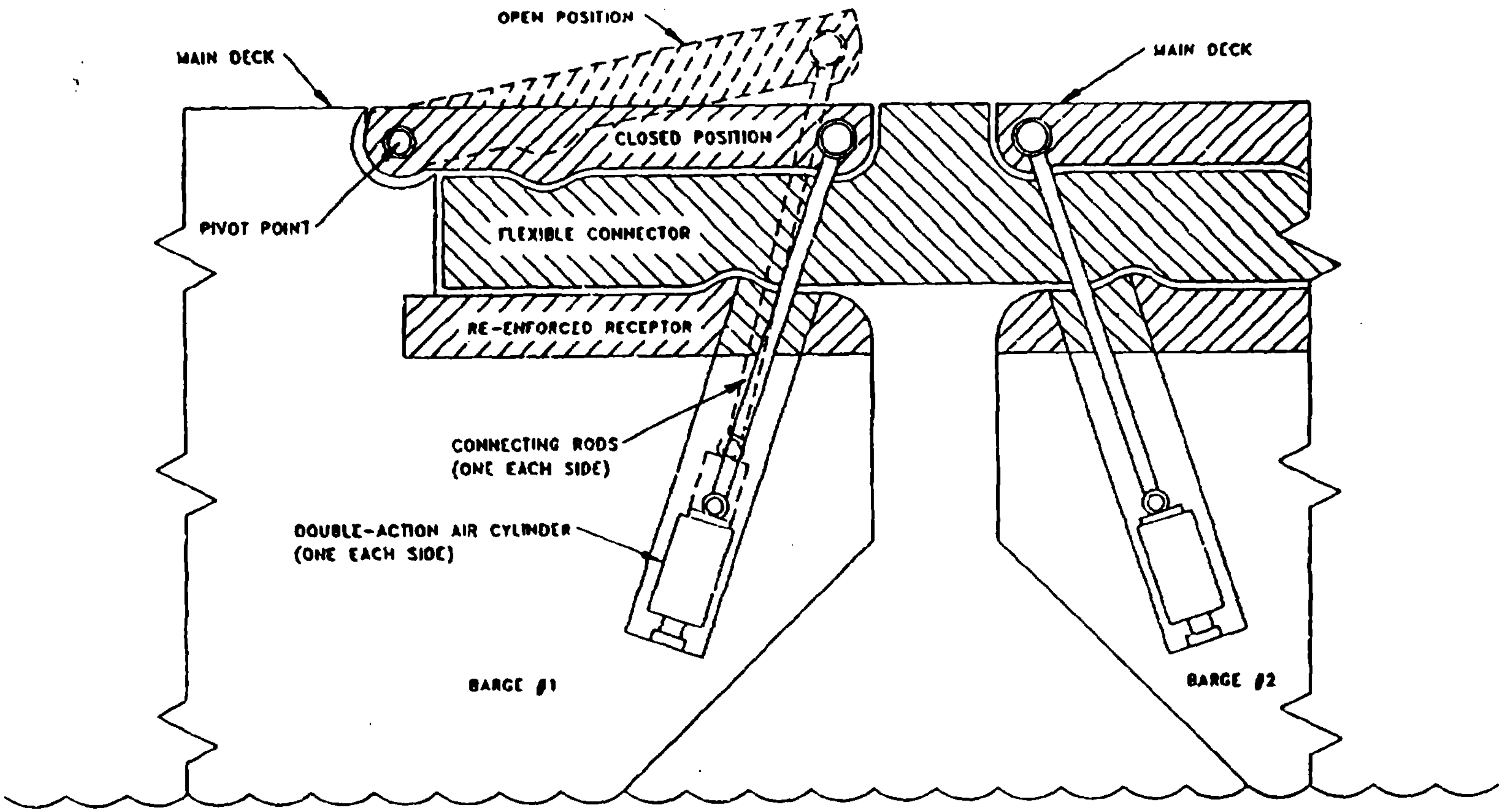
ADDITIONAL CONSIDERATIONS:

The following is a listing of several areas which require additional consideration and evaluation as development of this concept continues.

- Consider the use of a cruciform shape versus an inverted 'T' shape for the connectors. This would allow for better distribution of loads across the mating surfaces of the adjacent barges and to provide additional fendering between barges.



FLAT FLEXIBLE CONNECTOR
WITH MECHANICAL CLOSURE
DRAWING III-1



CROSS SECTION OF
FLAT FLEXIBLE CONNECTOR
WITH MECHANICAL CLOSURE
DRAWING III-2

APPENDIX A MATERIAL SPECIFICATIONS AND PROPERTIES

Manufacturer: GOODYEAR TIRE & RUBBER COMPANY			
		PRODUCT NAME	
PROPERTY	TEST METHOD	VERSIGARD (EPDM)	PLIOFLEX (SBR)
Min. Tensile Strength	ASTM D-412	2000 PSI	2000 PSI
Min. Elongation	ASTM D-412	300%	300%
Hardness Shore A Durometer	ASTM D-412	70 ± 5	70 ± 5
Modulus @ 300% Elongation	ASTM D-412	900 PSI Min	900 PSI Min
Heat Resistance	ASTM D-573 Max Change Hardness Max Change in Tensile Max Change in Ultimate Elongation	± 10 Pts - 25% - 25%	± 10 Pts - 25% - 25%
Compression Set	ASTM D-395 Method B	25% Max	25% Max
Ozone Resistance	ASTM D-1171	No Cracks	No Cracks
Water Resistance	ASTM D-471	10% Max Swell	10% Max Swell
Low Temperature Brittleness	ASTM D-2137 Non-brittle after 3 min @ -40°F Non-brittle after 3 min @ -67°F	Passes	Passes
Load Deflection	ASTM D-575 20% Deflection	300 ± 70 PSI	300 ± 70 PSI
Tear Resistance	ASTM D-624	200 PPI Min	200 PPI Min

TABLE 1

APPENDIX B MODULAR CONNECTOR TEST PROCEDURES

Proving the feasibility of any of the concepts presented in this report will require the following steps:

1. Prepare full design characteristics and capabilities for the connectors, receptors and associated components.

2. Solicit the services of a manufacturer with the capabilities of manufacturing a connector from a material similar to that as specified in this report, ie. Goodyear Tire and Rubber Co. This contractor will provide input on its design and construction

3. Prepare detailed design drawings.

4. Establish baseline test procedures to simulate actual working conditions to be expected on a 'deployed waterfront facility'.

5a. Develop a computer progra~ which can simulate actual working conditions; or

5b. Build a scale model or full size prototype connector with mating receptors.

6. Test either the computer simulated connector or actual connector under the following situations:

   a. Compressive loads to examine if this has the effect of loosening the connector within its receptor.

   b. Tensile loads to determine at what point the connector will begin to fail.

   c. Shearing or torsional loads.

   d. Apply different air pressures to the air bladder and apply a load to the connectors to see under what conditions and at what pressures slippage will occur.

   e. Apply a combination of the above loads.

   f. Finally, test the connector to destruction.

Total maximum loads (F_{ML}) anticipated on barge modules with a flexible connector system:

(F_{ML}) = 1,000 long tons (2,240,000 pounds)

1. <u>Rectangular Connectors</u>

Connector dimensions (overall):
14′ long x 14′ wide x 6′ deep (14" deep along each side)

Cross sectional area: (A_{CS}) 14′ wide x 14" deep = 2,352 sq in

Connector material:
Minimum tensile strength: (T_S) = 2,000 psi
Shearing strength: (S_S) = 900 psi @ max. elongation
Coefficient of friction: (C_f) = 0.6 (Assumed)

a. Strength per connector in tension: (F_T)

$F_T = T_S \times A_{CS}$
= 2,000 psi x 2,352 sq in
F_T = 4,700,000 lbs per connector

Assuming four (4) connectors across end of barge

Total tensile strength: (TF_T)
= 4,700,000 lbs/connector x 4 connectors = 18,800,000 lbs (8,400 long tons)

Factor of Safety

$$\frac{\text{Total Tensile Strength}}{\text{Maximum Load}} = \frac{TF_T}{F_{ML}} = \frac{8,400 \text{ long tons}}{1,000 \text{ long tons}}$$

Factor of Safety = 8.4:1

b. Holding capability of pneumatic air bladder system

Air bladder size:	10' long x 4' wide
Area of air bladder:	(A_B) = 5,760 sq in
Air pressure:	(P)
Coefficient of friction:	(C_f) = 0.6 (Assumed)

Holding force per connector: (F_{HC})

$C_f = \frac{F}{N}$ where F = friction force = Total max load (F_{ML}) &
N = total pressure on surfaces of connector
= P x A_B x 2 surfaces

$$C_f = \frac{F_{ML}}{P \times A_B \times 2}$$

$$P = \frac{F_{ML}}{C_f \times A_B \times 2}$$

$$= \frac{2,240,000 \text{ lbs}}{0.6 \times 5760 \text{ sq in} \times 2}$$

$$P = 324 \text{ psi}$$

Weight of rubber added to holding capability of connector:

Rubber weighs: 68 lbs/cu ft

Volume of rubber material above and below bladder:
10' long x 4' wide x 7" deep = 23.3 cu ft

Weight of rubber:
23.3 cu ft x 68 lbs/cu ft = 1,585 lbs
or 0.28 lbs/sq in

Based on C_f = 0.6, the additional friction force to overcome due to the weight of the rubber is equal to 0.168 lbs/sq in. (This amount is considered negligible.)

The above air pressure of 324 psi is the minimum amount of air pressure required in one air bladder for that one connector to withstand the entire maximum load of 1,000 long tons assumed acting on the barge modules. If it is assumed that the maximum loads will be distributed over at least two of the proposed four connectors at any one time the above air pressure could be reduced by one half.

Bladder air pressure required

$P = 324 \text{ psi} \times \frac{1}{2} = \mathbf{162\ psi}$

Holding capability of each connector based on an bladder air pressure of 162 psi, would be:

$$
\begin{aligned}
F_{HC} &= P \times A_B \times C_f \\
&= 162 \text{ psi} \times 5{,}760 \text{ sq in} \times 0.6 \\
&= 560{,}000 \text{ lbs} \times 2 \text{ surfaces per connector} \\
F_{HC} &= \mathbf{1{,}120{,}000\ lbs\ per\ connector}
\end{aligned}
$$

Utilizing four (4) connectors

Total holding capability (TF_{HC})

$TF_{HC} = 1{,}120{,}000$ lbs per connector x 4 connectors

TF_{HC} = 4,480,000 lbs (2,000 long tons) *

* This does not take into consideration the increased holding capability due to the recessed areas built into the top and bottom surfaces of the receptors or any pattern or shape incorporated into these surfaces.

Factor of Safety

$$\frac{\text{Total Holding Capability}}{\text{Maximum Load}} = \frac{TF_{HC}}{F_{ML}} = \frac{2{,}000 \text{ long tons}}{1{,}000 \text{ long tons}}$$

Factor of Safety = 2.0:1

c. Shearing strength per connector (F_S)

Shearing strength of material:
(S_S) = 900 psi @ max elongation

$F_S = S_S \times A_{CS}$
$= 900$ psi x 2,352 sq in

F_S = 2,115,000 lbs per connector

Utilizing four (4) connectors
Total shearing strength (TF_S)

TF_S = 2,115,000 lbs x 4 connectors

TF_S = 8,460,000 lbs (3,777 long tons)

Factor of Safety

$$\frac{\text{Total Shearing Strength}}{\text{Maximum Load}} = \frac{TF_S}{F_{ML}} = \frac{3{,}777 \text{ long tons}}{1{,}000 \text{ long tons}}$$

Factor of Safety = 3.8:1

2. Cylindrical Connectors

Connector dimensions of cylindrical sections: (overall)
20′ long x 4′ diameter

Cross sectional area: $(A_\phi) = \frac{\pi D^2}{4}$

Based on 4′ diameter (A_ϕ) = 1,800 sq in

Connector material:
Minimum tensile strength: (T_S) = 2,000 psi
Shearing strength: (S_S) = 900 psi @ max. elongation

a. Strength per connector in tension: (F_T)

$$F_T = T_S \times A_\phi$$
$$= 2{,}000 \text{ psi} \times 1{,}800 \text{ sq in}$$

F_T = 3,600,000 lbs per connector

At least five connectors would be necessary to match the tensile strength of the rectangular connectors. However, due to the reduced surface area of the cylindrical receptor, relative to the holding capability discussed in the next section, eight of these connectors are being proposed.

Total tensile strength: (TF_T)
3,600,000 lbs/connector x 8 connectors = 28,800,000 lbs
(12,857 long tons)

Factor of Safety

$$\frac{\text{Total Tensile Strength}}{\text{Maximum Load}} = \frac{TF_T}{F_{ML}} = \frac{12{,}857 \text{ long tons}}{1{,}000 \text{ long tons}}$$

Factor of Safety = 12.85:1

b. Holding capability of pneumatic air bladder system

Air bladder size: 8′ long x 40" diameter

Area of air bladder: (A_B) = 12,000 sq in

Air pressure: (P)

Coefficient of friction: (C_f) = 0.6 (Assumed)

Holding force per connector: (F_{HC})

$C_f = \frac{F}{N}$ where F = friction force = Total max load (F_{ML}) &

N = total pressure on surfaces of connector $= P \times A_B$

$$C_f = \frac{F_{ML}}{P \times A_B}$$

$$P = \frac{F_{ML}}{C_f \times A_B}$$

$$= \frac{2,240,000 \text{ lbs}}{0.6 \times 12,000 \text{ sq in}}$$

$$P = 311 \text{ psi}$$

The above air pressure of 311 psi is the minimum amount of air pressure required in one air bladder for that one connector to withstand the entire maximum load of 1,000 long tons assumed acting on the barge modules. If it is assumed that the maximum loads will be distributed over at least two of the proposed eight connectors at any one time the above air pressure could be reduced by one half.

Bladder air pressure required

$$P = 311 \text{ psi} \times \tfrac{1}{2} = 156 \text{ psi}$$

Holding capability of each two connectors based on an bladder air pressure of 156 psi, would be:

$F_{HC} = P \times A_B \times C_f$

$= 156 \text{ psi} \times 12,000 \text{ sq in} \times 0.6$

F_{HC} = 1,120,000 lbs per two connectors

Utilizing eight (8) connectors

Total holding capability (TF_{HC})
TF_{HC} = 1,120,000 lbs per two connectors x 8 connectors

TF_{HC} = 4,480,000 lbs (2,000 long tons) *

* This does not take into consideration the increased holding capability due to the recessed areas built into the top and bottom surfaces of the receptors or any pattern or shape incorporated into these surfaces.

Factor of Safety

$$\frac{\text{Total Holding Capability}}{\text{Maximum Load}} = \frac{TF_{HC}}{F_{ML}} = \frac{2{,}000 \text{ long tons}}{1{,}000 \text{ long tons}}$$

Factor of Safety = 2.0:1

c. Shearing strength per connector: (F_s)

Shearing strength of material:
(S_s) = 900 psi @ max elongation

$F_s = S_s \times A_4$
= 900 psi x 1,800 sq in

F_s = 1,620,000 lbs per connector

Utilizing eight (8) connectors

Total shearing strength (TF_s)

TF_s = 1,620,000 lbs x 8 connectors

TF_s = 12,960,000 lbs (5,786 long tons)

Factor of Safety

$$\frac{\text{Total Shearing Strength}}{\text{Maximum Load}} = \frac{TF_s}{F_{ML}} = \frac{5{,}786 \text{ long tons}}{1{,}000 \text{ long tons}}$$

Factor of Safety = 5.8:1

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